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# Construction of an AI electronic nose system for characterization of a coffee aroma map in Chiang Rai province

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**Abstract** - Chiang Rai, a province located in northern Thailand, has gained renown for its exclusive Arabica coffee fragrance, attributed to the region's elevated climate and distinctive topography. In a concerted effort to elevate the worth of this aromatic treasure, a dedicated team of researchers pioneered an AI-based electronic olfaction system. The system is equipped with an array of gas sensors, meticulously calibrated to detect gases within the 10-1000 ppm range, encompassing the ten distinct gases released by coffee beans. These highly sensitive detectors are seamlessly interfaced with an Arduino ESP32 processor board and under the precise orchestration of a Python program. The system promptly responds to the sensors, meticulously gauging the nuances of the coffee aroma. Subsequently, this data is transmitted *via* Wi-Fi, utilizing the Internet of Things (IoT) protocol. Further, the collected information is securely deposited within a cloud-based web service, offering real-time access through an online platform. These sophisticated aroma maps serve as invaluable resources, unraveling

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the distinctive olfactory profiles of coffee beans cultivated across varied regions of Chiang Rai. The cumulative data serves as a cornerstone for the development of AI-driven electronic olfaction systems, tailored to identify the singular aromas of coffee beans unique to this locale. This technological leap not only enriches the repository of coffee aroma maps but also augments the inherent value of Chiang Rai's coffee bean production. Additionally, these aroma maps serve a dual purpose by bolstering the branding and marketing endeavors of Chiang Rai's coffee beans, rendering them easily recognizable and enticing to a global consumer audience.

**Keywords:** AI electronic noses, gas sensor detectors, Arduino ESP32

## 1. Introduction

Globally, coffee is one of the most popular beverages, with approximately 2.25 billion cups consumed per day (ICO, 2021). People delight in the complex flavors and aromatic scents influenced by various factors, including coffee bean varieties, cultivation conditions, processing methods, roasting levels, and brewing techniques (Illy, 2005; Münchow *et al.*, 2020). Among these factors, the aroma of coffee may hold the utmost significance as it serves as a preliminary indicator of taste and beverage quality. The aroma of coffee is a complex blend of hundreds of volatile organic compounds (VOCs) that are released during the roasting and brewing processes (Farah, 2012; Chen *et al.*, 2022). These compounds interact with the olfactory receptors in the nose, resulting in the familiar and enjoyable coffee fragrance. The specific components and intensity of VOCs in coffee aroma can vary depending on factors such as roasting levels, bean varieties, and brewing methods (Lehane, 2018; Barea-Ramos, 2022; dos Santos, 2022), making them essential markers for origin, processing, and coffee quality. Professional coffee tasters, also known as "cuppers," rely primarily on the aroma of coffee to evaluate its quality and sensory attributes (Illy, 2005; Pereira, 2021). Coffee brewers can distinguish subtle differences in aromas between various coffee samples, identifying scents of fruits, flowers, spices, hot peppers, earthiness, and more (Specialty Coffee Association of America (SCAA), 2021). These experts undergo extensive training to develop keen olfactory perception and memory and utilize standardized protocols and descriptors to ensure consistency and objectivity in evaluations (Specialty Coffee Association of America (SCAA), 2021).

Despite the importance of coffee aroma in sensory analysis and quality control, evaluating aroma remains a challenging task due to its complexity and variability. Human assessors have limited sensitivity and perception, which can be influenced by various factors such as fatigue, food, smoking, and environmental conditions (Bhumiratana, 2017; Seninde, 2020, Rocchetti, 2020; Elhalis, 2021). Moreover, sensory evaluations are time-consuming, expensive, and require well-trained personnel, making large-scale production and quality checks impractical.

Researchers have explored the possibility of using electronic noses as an alternative for human olfactory analysis of coffee aroma. Electronic noses mimic the human olfactory system by combining multiple gas sensors with pattern recognition algorithms to identify and discriminate complex odor profiles (Gardner, 1994;

Borowik, 2020; Bonah, 2020). Electronic noses have found applications in various fields, including food quality control, environmental monitoring, medical diagnosis, and security (Di Natale, 2003; Karakaya, 2020; John, 2021). In the context of coffee aroma analysis, electronic noses offer several advantages, such as speed and reproducibility, surpassing human evaluators in these aspects (Rocha, 2018). Furthermore, electronic noses can detect odor compounds that are challenging for humans to perceive, such as trace amounts of acetic acid, nitrogen, or oxygen compounds (Ferreira, 2016; Dung, 2018). Recent studies have demonstrated that electronic noses can differentiate coffee bean varieties, roasting levels, and brewing methods based on their distinctive aromas (Lai, 2020; Yamanaka, 2020). However, most of these studies have focused on laboratory-based experiments using standardized samples, which may not fully capture the complexity and diversity of real-world coffee products.

In this research report, we present an AI-powered electronic nose system that detects gases in coffee beans using multiple gas sensors, covering ten different gases. The system aims to characterize the aroma of coffee beans, providing valuable insights into coffee origin and quality. This research focuses on innovating an electronic nose system for measuring gases and chemical compounds emitted by coffee beans. The system is designed to be lightweight, compact, and affordable, with a small processing board. Small-scale coffee producers and farmers can use this device to assess the quality of coffee beans based on their aroma. Additionally, it can assist baristas in blending coffee beans to create new and unique coffee flavors in their coffee shops.

## 2. Materials and methods

This research consisted of two main parts. The first part involved designing and creating an AI-powered electronic nose system to characterize the specific aroma profiles of coffee. The system included a set of gas sensors, namely MG-811, MQ131, MQ136, MQ137, MQ138, MQ9, MQ8, MQ3, MQ135, and MQ7, capable of detecting gas concentrations in the range of 10-1000 ppm. These gas sensors were connected to an Arduino ESP32 microcontroller board and controlled by a Python program. The electronic nose system was responsive to the coffee aroma and sends data over the internet via Wi-Fi using the IoT (Internet of Things) protocol. Next, the data collected by the electronic nose system was stored on a cloud web service, and real-time results were displayed on an online website in the form of a coffee aroma map, as shown in Figure 1. In the second part, the AI-powered electronic nose system was tested with different coffee aromas from three distinct geographical locations. - (1) an area with elephants, (2) Doi Pang Khon area, and (3) Doi Tung area. The system recorded measurements from all ten gas sensors and calculated the average values. These data were then used to generate radar charts, displaying the aroma profiles of coffee from each geographical location. The aroma map data were stored in a database for further development of the AI-powered electronic nose system, as depicted in Figure 2.

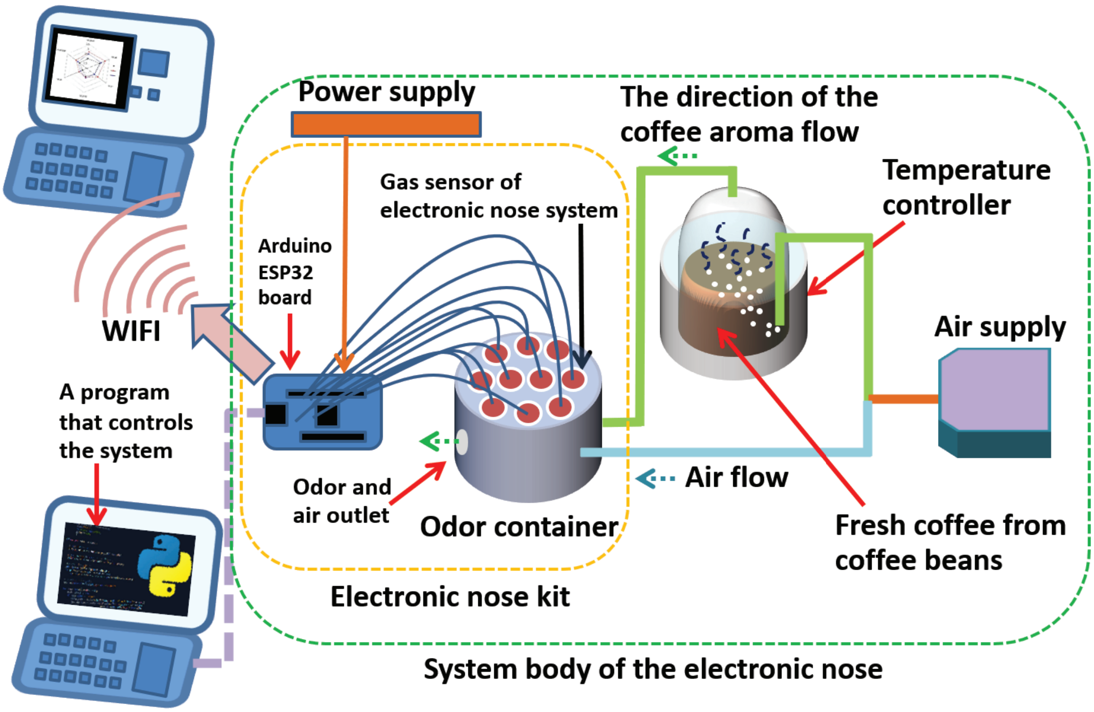


**Figure 1.** Explain the operation and components of the AI-powered electronic nose system for characterizing specific aroma profiles of coffee.

## 2.1 Coffee bean aroma emission

The test process begins with placing the coffee beans to be measured in an electronic nose system, specifically designed for this purpose. Coffee beans emit their distinctive aroma when they are in a normal state or undergo aroma measurement in Figure 2.

## 2.2 Gas sensor detects coffee aroma

A gas sensor was employed to receive and detect the coffee aroma. The sensor's primary function was to analyze the chemical compounds present in the coffee aroma.

## 2.3 Conversion to electrical voltage

The coffee aroma was transformed into an electrical voltage. This conversion was directly proportional to the intensity of the coffee aroma detected.

## 2.4 Transmission to ESP32 board

The electrical voltage data obtained from the gas sensor was transmitted to an ESP32 board for data processing.

## 2.5 ESP32 transmits Wi-Fi signals

The ESP32 board establishes a Wi-Fi connection and communicates with an internet network.

## 2.6 IoT protocol transmission

The data from the ESP32 was transmitted using the Internet of Things (IoT) protocol to an internet-based service that handles data storage (Misra, 2022; Park, 2023). Cloud Web Service for Data Storage: Data sent from the ESP32 was securely stored in a cloud-based service accessible *via* the internet, ensuring convenient data management and access.

## 2.7 Real-Time data reporting

The electrical voltage data, acquired through real-time coffee aroma measurements was presented in real-time on a web-based platform. Users can conveniently monitor this data in real-time.

## 2.8 Graphical representation of average electrical voltage

Preliminary data regarding the average electrical voltage associated with the coffee aroma was graphically displayed on the website, providing users with a comprehensive overview of the information.

## 2.9 Detailed analysis results

Additionally, detailed analysis results of individual samples of coffee aroma obtained through the measurement process are presented on the website, allowing users to explore and understand the data in-depth. A substantial amount of coffee aroma sample data from years of research, which requires extended periods of accumulating experience, is crucial for the recording and learning process of the AI-powered electronic nose system. This data has been detected and recorded in the Cloud Web Service for Data Storage. It will be retrieved for further development in the next phase to enhance the AI-powered electronic nose system.

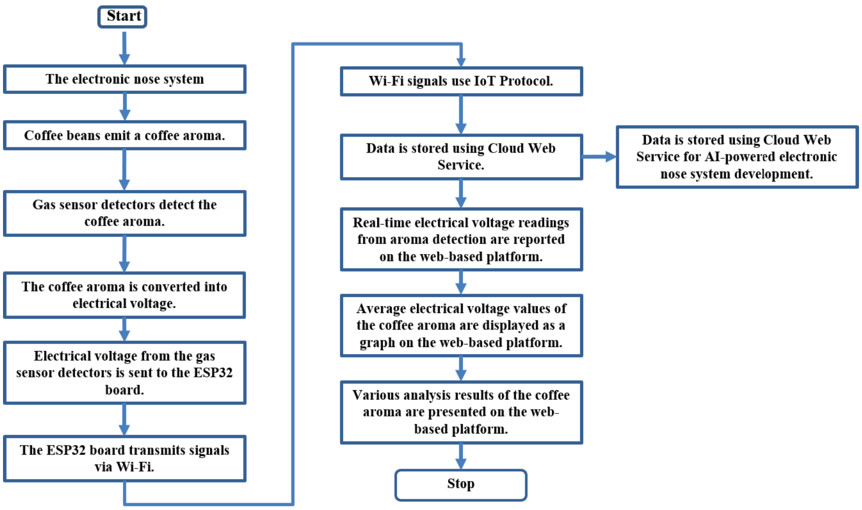


**Figure 2.** Explain the operation of the AI-powered electronic nose system for characterizing specific aroma profiles of coffee, including data transmission and presentation on a website**.**

## 3. Results and discussion

The research results in step 1. The Arduino ESP32 board is a microcontroller board used in the Internet of Things (IoT) context, capable of efficient Wi-Fi connectivity. The ESP32 features a high-speed Wi-Fi module, enabling easy and high-performance connection to Wi-Fi networks. It is particularly suitable for electronic projects that require straightforward Wi-Fi connectivity, such as monitoring the aroma of coffee in the field at a coffee shop. The ESP32 has the ability to manage data and communicate through various protocols over Wi-Fi, such as HTTP, MQTT, and CoAP. This facilitates the easy and efficient transmission of data from gas sensors or control of devices. The ESP32 also excels in energy management, efficiently conserving power by switching between full-power operation and low-power modes. This is beneficial for saving energy when maintaining Wi-Fi connectivity during waiting periods, such as when preparing coffee aroma under various conditions, while still needing constant communication between the control panel and the electronic olfactory sensor for real-time status display. Furthermore, the ESP32 offers multiple I/O pins that can be used to control various devices. This makes it well-suited for simultaneously reading data from multiple sensors and provides versatility in connecting external hardware.

The Arduino ESP32 board relies on a Wi-Fi connection, and if it cannot establish a Wi-Fi connection, such as due to weak or missing Wi-Fi signals, our electronic olfactory system, which operates as an IoT system, may experience limitations in terms of connectivity and communication. This can lead to it not functioning at its full potential or not functioning at all. However, it should be noted that coffee shops typically have Wi-Fi signals available for customer use on a consistent basis, which can help mitigate the issue unless unexpected circumstances arise.

### 3.1 The design and creation of the AI-powered electronic nose system for characterizing specific aroma profiles of coffee.

This system includes the electronic nose device, as shown in Figure 3, with a status display screen and internal functionalities. Additionally, a website has been developed at https://coffee.chiangeyes.com/ to present the measurement results of coffee aroma, as depicted in Figure 4. (a) The website allows authorized access to measurement data by operators using the AI-powered electronic nose system. (b) It provides a menu for selecting different testing conditions and criteria for aroma detection. (c) The website displays real-time examples of coffee aroma maps detected by the AI-powered electronic nose system. (d) The website also allows the designation of testing locations in the field, enabling the storage of aroma maps correlated to specific coffee plantation areas.

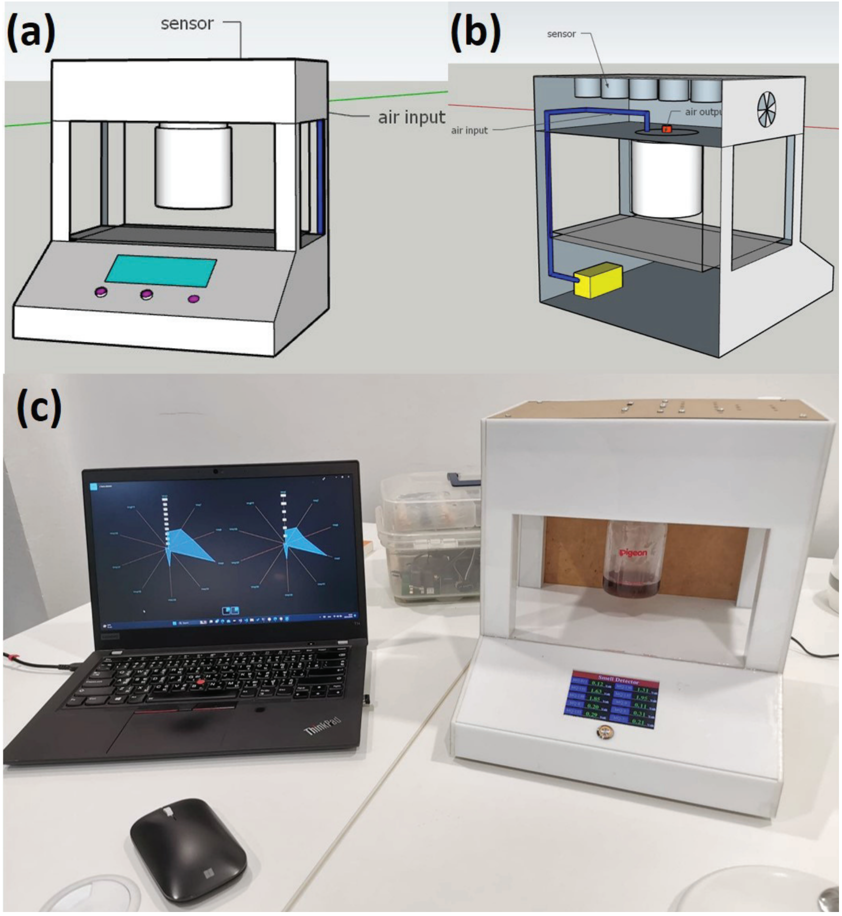


**Figure 3.** The results of the design and construction of the front and back views of the electronic nose device are shown in (a) and (b) respectively. The prototype device has successfully detected the aroma of Arabica coffee from the coffee sample as shown in (c).

## 3.2 The results of the research in step 2

The testing outcomes of the AI-powered electronic nose system, which were preliminarily evaluated with different coffee aromas from three geographically distinct regions Doi Pang Khon area the preliminary analysis, notable differences in aroma profiles were observed among the regions, requiring further confirmation through an increased number of measurement samples and comparison with evaluations conducted by expert coffee tasters in subsequent phases.

This part explains that the outcomes or findings of the process involved in creating an AI-powered electronic nose system, designed for the purpose of identifying and describing unique coffee aroma profiles, have been successfully gathered. These results come from the electronic nose device, a piece of technology used for sensing and analyzing smells, and they are made available for public viewing on a designated website marked as in Figure 4(a).

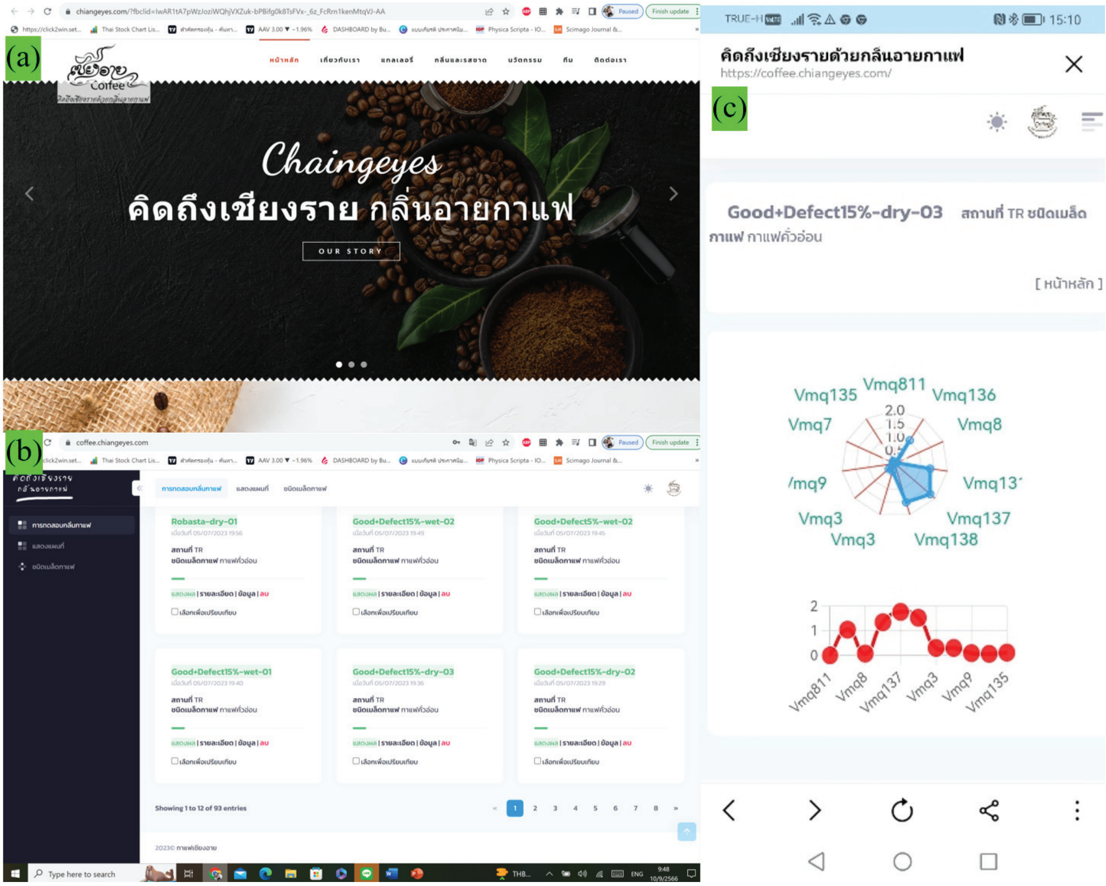


**Figure 4.** The results of designing and constructing the AI-powered electronic nose system to characterize specific coffee aroma profiles have been obtained from the electronic nose device and are showcased on the website (a). Furthermore, a log of recorded data, including samples of coffee aroma for in-depth analysis, is available (b). These resources are accessible on smartphones, allowing for field operations (e).

In simpler terms, it means that the data obtained from the electronic nose system's operation is now accessible to anyone visiting the specified website. In addition to the results mentioned in the first part, this section mentions the existence of a detailed record or log. This log contains various types of data, which include samples of coffee aromas. These samples are preserved for thorough examination and analysis. This data resource is specifically labeled as Figure 4(b), indicating it can be accessed separately. Essentially, it suggests that not only are the results available but also a comprehensive dataset, which includes coffee aroma samples for more profound research and understanding in Figure 4(b). This final part underscores the accessibility of the mentioned resources on smartphones. It means that individuals can access both the results and the detailed data log, including aroma samples, using their smartphones. This accessibility is particularly useful for conducting operations or research in the field, where individuals can refer to this information directly on their mobile devices. It emphasizes the convenience of having this valuable data at one's fingertips while working outside of a traditional office or lab environment in Figure 4(c). This system is fully functional and capable of recording aroma maps of coffee to develop a comprehensive AI-powered electronic nose system.

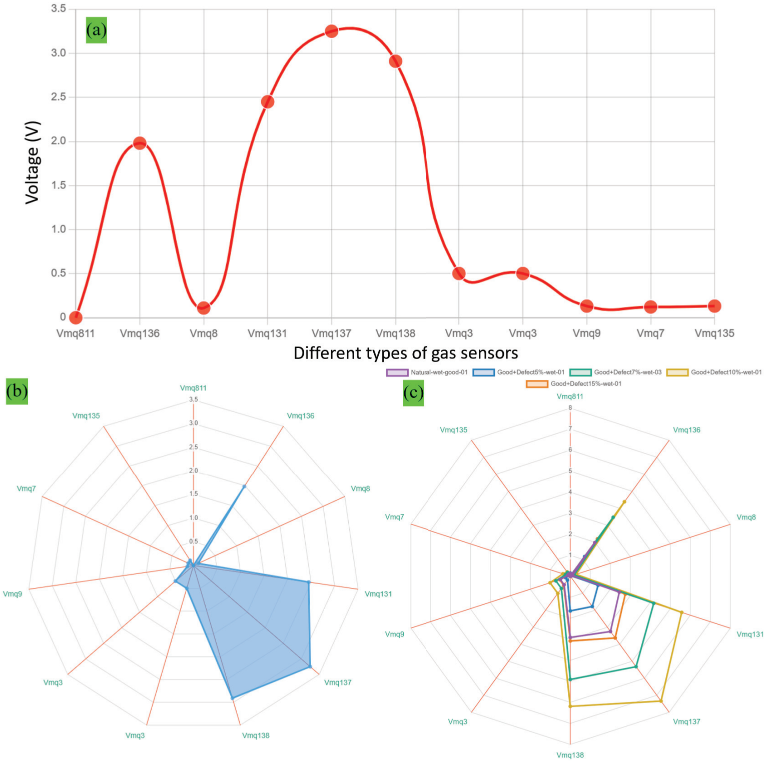


**Figure 5.** The results of coffee aroma detection are presented, as reported on the webpage in the form of a graph displaying the electrical voltage values from ten electronic nose sensors (a). Subsequently, the voltage values are transformed into a contour graph, illustrating the spatial distribution of Arabica coffee aroma (b). Additionally, the figure demonstrates the outcomes of comparative testing, highlighting the aroma distribution differences between high-quality coffee beans and those with contamination levels of 0%, 5%, 7%, 10%, and 15%, respectively.

This part explains that the outcomes of a process involving the detection of coffee aromas are showcased and discussed. These results are made available on a webpage, specifically identified as Figure 5(a). To visually represent the data, a graph is employed. This graph displays electrical voltage values, which have been collected from ten electronic nose sensors. In essence, it means that the data collected from the electronic nose sensors is converted into a graph format and displayed on a website for users to view. Following the presentation of the initial graph, the text mentions that the voltage values were subjected to a transformation process. This transformation results in the creation of a contour graph. This graph was designed to visually represent the spatial distribution of Arabica coffee aroma. Essentially, it provides a graphical depiction of how the aroma is distributed across a particular area or surface. This graph is specifically labeled as Figure 5(b). In this final part, the text mentions that the figure (which likely includes the graphs mentioned earlier) serves an additional purpose. It is used to illustrate the results of comparative testing. Specifically, it highlights the differences in aroma distribution between high-quality coffee beans and beans with various contamination levels. The text specifies the contamination levels tested: 0%, 5%, 7%, 10%, and 15%. This means that the figure (possibly in the form of additional graphs or charts) visually demonstrates how the aroma profiles of coffee beans change when they are contaminated at these different levels Figure 5(c).

## 4. Conclusion

This research project has successfully designed and created an AI-powered electronic nose system. The electronic nose device consists of a set of gas sensor heads, encompassing various types of gases released from coffee beans. There are ten sensor heads capable of detecting gas concentrations in the range of 10-1000 ppm. These gas sensor heads are connected to an Arduino ESP32 processing board, which is controlled by a Python program. The electronic nose system is responsive to the coffee aroma and can perform odor measurements. The system is equipped with internet Wi-Fi capabilities and uses IoT (Internet of Things) Protocol to transmit data in real-time. The collected data is then stored on a cloud web service. The results are displayed on an online website as a real-time aroma map of coffee. This electronic nose system can differentiate the aroma of Arabica coffee, even at varying levels of contamination, making it suitable for assessing the quality of coffee beans. This system is fully functional and capable of recording aroma maps of coffee to develop a comprehensive AI-powered electronic nose system. The aroma maps are generated from coffee beans sourced from different geographical areas in Chiang Rai province, such as Doi Pang Khon. The research findings demonstrate the potential to add value to coffee beans by promoting unique coffee aromas based on their geographical origin within the Chiang Rai region.

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